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Extended Abstract

Utilizing Routine Water Quality Instruments and Artificial Neural Networks for Monitoring Distribution System Security

Topical Focus: Emerging Issues Related to Water Security

Drinking water system security concerns have been a considerable issue in the United States in recent years, but in the last two years this issue has risen to new levels of urgency. The tragic events of September 11th highlighted America's vulnerability to terrorism and spurred a domestic security response unprecedented since World War II. Drinking water systems were identified almost immediately as a potential target for future attacks and were urged by the FBI to implement security measures. To address these threats, research and development efforts aimed at new technology for contaminant specific detection have increased significantly. Even though considerable additional research in this area is needed, there are concerns about this technology due to the potential costs, and the specificity of the monitoring being easily defeated. Currently, significant purposeful contamination of a water system won't be properly characterized until post-symptomatic epidemiological events are manifested in the affected community. Most drinking water systems currently monitor a significant number of water quality parameters at the plant. These are required for compliance and maintenance of water quality as the water enters the distribution system. In the distribution system, water quality is usually monitored through grab samples with an analysis turn-around time of hours to days.

The threat of chemical or microbiological contamination to drinking water is well established, and would be an effective way of causing devastating public health consequences (Khan et al., 2001; Teter, 2002). As it presently stands, the technology to detect these contaminants is lacking (Tiemann, 2002). Early detection of these contaminants via on-line or real-time monitoring has been identified as a feasible way to provide early warning to protect public health (Luthy, 2002; USEPA, 2002; Deininger et al., 2000).

Take for example, a distribution system that is compromised by the introduction of a large quantity of a toxic contaminant. Shortly after this purposeful contamination event, the on-line monitoring equipment detects significant changes from the baseline in conductivity, pH, total organic carbon, turbidity, and/or chlorine residual--or more likely, two or more of these parameters. By utilizing a trained artificial neural network and monitoring distribution system water quality real-time, the plant operator will be able to quickly realize that a contamination event has occurred in the distribution system. The contaminant in the system will not be

specifically identified but the utility can begin the process of isolating the event and determining the cause. The significance of this ability is timely response and mitigation to expedite the return of the water system back to service, and to inform the public health agencies expeditiously to help in diagnosis if remedial action isn't taken quickly enough. This capability is also applicable to daily water quality monitoring. Results of this research could be used with more common contamination events such as backflow, line breaks, iron from heavily tuberculated cast-iron mains, and sloughed-off biofilm, to name a few.

The primary objective of this research is to develop a methodology for the real-time detection of significant disturbances in a drinking water distribution system. In particular, the research will be aimed at detecting intentional chemical and biological contamination events. The primary objective will be accomplished by combining routine monitoring instruments that are readily available and relatively inexpensive (pH, conductivity, chlorine residual, turbidity, TOC) with the advanced data analysis technique of artificial neural networks (ANN).

This research effort will first establish baseline water quality conditions, and use this baseline to train an ANN on what is considered "normal." Then the following credible threat contaminants: sodium cyanide, sodium arsenate, sodium fluoroacetate, parathion, *Cryptosporidium parvum* oocyts, and a surrogate of *Bacillus anthracis* spores, will be introduced into a pilot drinking water distribution system, one at a time, at different concentrations. *Direct* changes in pH, conductivity, chlorine residual, turbidity, and/or TOC will be detected, and the trained ANN will note an anomaly. The next set of experiments will include the addition of a rotating annular reactor with an established biofilm growth containing PVC coupons in series with the distribution system to take into consideration the microbiological impacts of the system. After the contaminant is introduced, *in*direct changes, likely turbidity and/or TOC will result from the exposure, death, and sloughing-off of biofilm due to the introduction of the contaminant. Again, the trained ANN will note an anomaly, from both the direct and indirect changes to the water quality. The ANN pattern recognition techniques that will be employed for the analysis of this data will be critical to increasing the ability to discern changes in water quality at relatively low concentrations.

Toxicity, water solubility, stability, low level of detectability, chlorine or oxidant resistance, availability to the saboteur, and a lack of taste, color and odor, are all important properties of a credible threat contaminant. These properties, in addition to literature review and coordination with others is key to identifying the contaminants mentioned above as credible drinking water threats to be used in this research. Of the chemical contaminants, two organics and two inorganics were selected. Of the microbiological contaminants, *Bacillus anthracis* spores and *Cryptosporidium parvum* oocysts are amongst the greatest water threat agents due to their infectivity, oxidant resistance, ability to withstand environmental stresses, and availability.

Preliminary results obtained while introducing three potential chemical contaminants to tap water in beaker tests are provided in Table 1. They provide an indication of direct contaminant-instrument response for selected contaminants, and will be key to zeroing in on the detection level of these contaminants using on-line monitoring equipment. NA is not applicable, NSC represents no significant change.

	Sodium Fluoroacetate	Sodium Cyanide	Sodium Arsenate
pH	slight decrease	increased	slight decrease
TOC	increased	NA	NA
Conductivity	increased	increased	increased
Chlorine Residual	decreased	eliminated	slight decrease
Turbidity	NSC	NSC	NSC

Table 1: Contaminant-Instrument Response with Increasing Concentration

As Table 1, Figure 1, and Figure 2 demonstrate, the potential to detect water threat contaminants using standard water quality parameters is significant. Turbidity wasn't effective as an indicator for these tests, but potential may lie ahead for detection of microbiological contamination and sloughed-off biofilm. Figures 1 and 2 reflect calculated changes in pH for increasing concentrations of inorganic contaminants in tap water, and changes in TOC for increasing concentrations of organic contaminants in tap water, respectively.
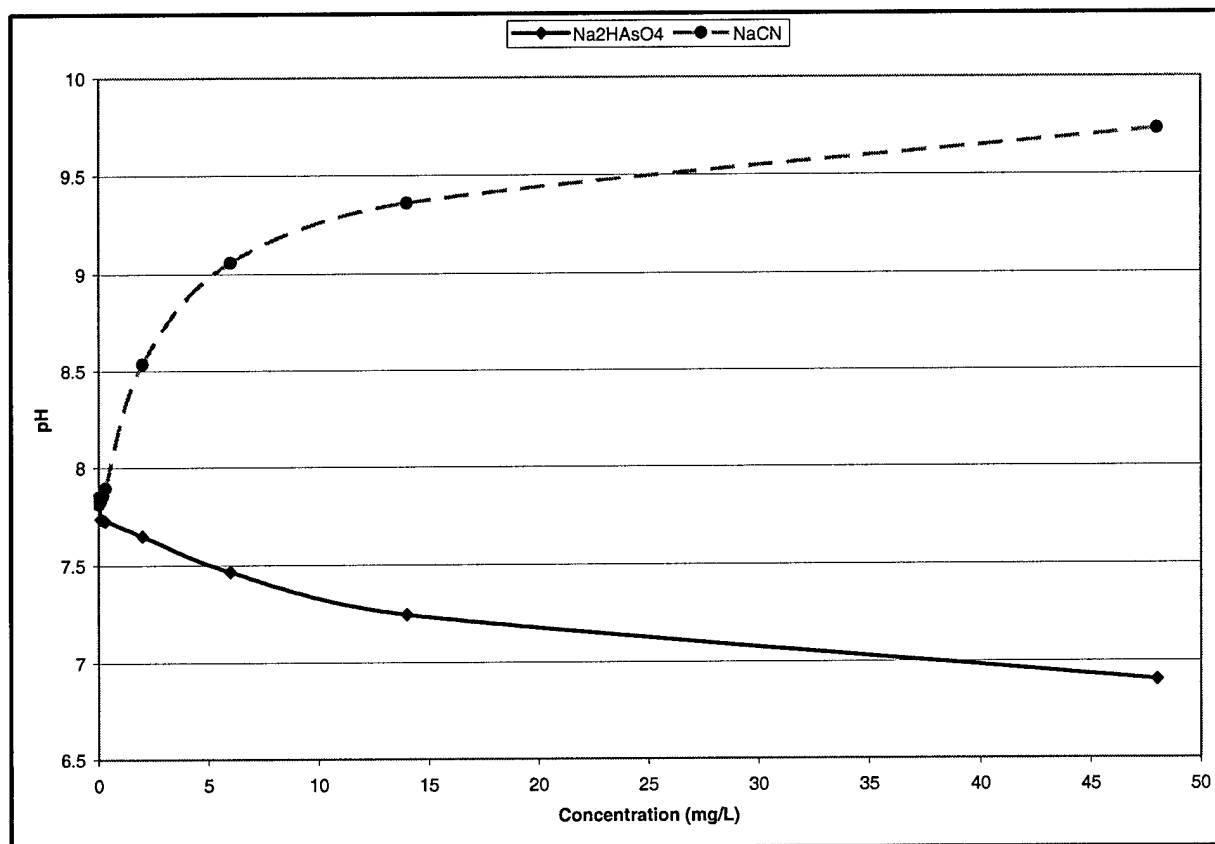

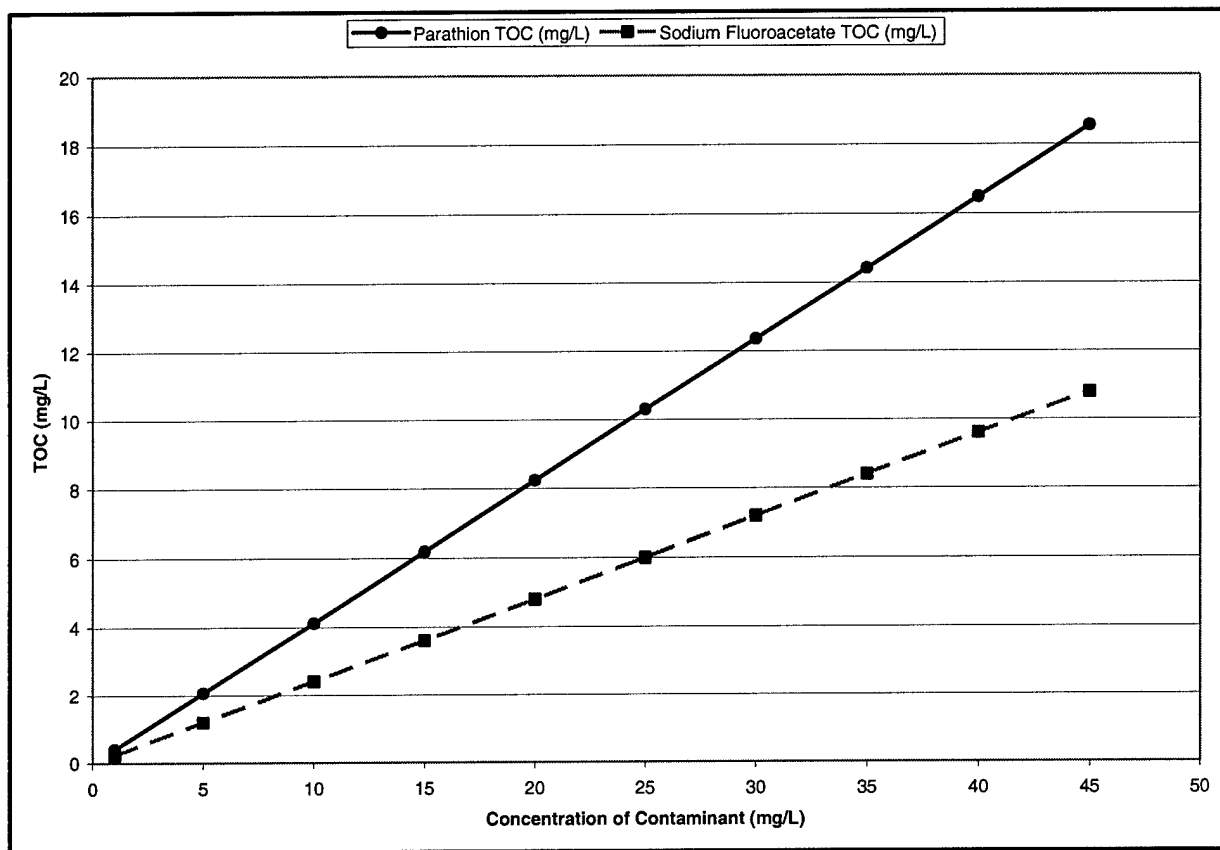**Figure 1:** pH Changes with Addition of Inorganic Contaminants to Tap Water

Figure 2: TOC Changes with Addition of Organic Contaminants to Tap Water

Drinking water distribution systems can not be characterized or simulated thoroughly without consideration of the microbiological factors, particularly biofilm. Biofilms likely exist in all distribution system pipes, are recognized as part of the normal aquatic system, and are introduced into the distribution system by well-treated, but non-sterile water (USEPA, 1992). The favorable microenvironment within the biofilm matrix provides protection to microbial cells from disinfectants. This is a key part of this study, as the protection normally offered by the biofilm will be compromised with the introduction of very toxic contaminants at relatively high concentrations, and it is expected that the biofilm will slough-off and will be quantified as either an increase in turbidity or TOC.

In summary, the research that is presented here attempts to address the cost and contaminant-specific issues mentioned previously. The basic premise of this research is that readily available and relatively inexpensive equipment can be used with advanced data analysis techniques such as ANN to determine when a contamination event in a distribution system has occurred. In other words, collect the same data we have been collecting but extract more *information* from this data to satisfy a critical need of the water industry: distribution system security.

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